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DR. R. C. SUTCLIFFE, F.R.S.

By SIR GRAHAM SUTTON, C.B.E., D.Sc., F.R.S.

Dr. R. C. Sutcliffe, Deputy Director (Research) of the Meteorological Office, was elected a Fellow of the Royal Society on March 21.

This recognition of Dr. Sutcliffe's outstanding position in synoptic research is the culminating point of a career wholly devoted to professional meteorology. Dr. Sutcliffe joined the Meteorological Office in 1927, and quickly made his way to the fore as a leading forecaster. His services with Bomber Command and the 2nd Tactical Air Force during the war enhanced his reputation as an exceptionally able practical meteorologist.

Although he had published some noteworthy papers and a well-known text book, "Meteorology for aviators", before the war, it was when active operations had ceased, and he had taken up the post of Assistant Director (Forecasting Research), that Dr. Sutcliffe's gifts as a mathematician began to make his reputation in the field of synoptic research. In 1947 he published his best-known paper "A contribution to the theory of development". This paper, and its successor, "The theory and use of upper-air thickness patterns in forecasting", written jointly with Dr. Forsdyke, have had a considerable influence on meteorological thinking, especially in the rapidly developing field of numerical forecasting, much of which, to quote a well known American worker in this field, is "in the spirit of Sutcliffe's work". These papers were quickly followed by other notable contributions, but in recent years Dr. Sutcliffe has turned his attention more to the problems of the largest-scale movements of the atmosphere, especially the general circulation. It is the hope and expectation of meteorologists that his work in this field, that of dynamical climatology, will also prove significant.

The F.R.S. is usually awarded for individual research, but it also reflects, in some measure, the esteem in which a particular study is held in the world of science generally. Dr. Sutcliffe's achievements have been almost entirely in the field of synoptic meteorology and it is, I think, not unreasonable to regard his election as evidence that the forecasting of weather is now generally regarded as a true science, taxing the utmost skill of the mathematician and the physicist, and thus worthy to be ranked with any other branch of geophysics.

The Meteorological Office now has a strong and well-equipped research side, and with the direction of the work in the hands of one who so happily combines great technical ability with a lively imagination and a long record of practical experience, the further outlook is good.

METEOROLOGICAL OFFICE DISCUSSION

Synoptic meteorology of the polar regions

The discussion, which was held at the Royal Society of Arts on Monday, December 17, 1956, was opened by Mr. R. A. Hamilton and Mr. H. H. Lamb.

Mr. Hamilton introduced the subject with a description of the salient geographical characteristics of the northern polar regions and main features of the annual heat budget within them. Mr. Lamb dealt mainly with the Antarctic and with comparisons between Arctic and Antarctic.

The total solar radiation reaching the outer atmosphere over the equator in any year is about two and a half times that over the pole. Over the equator the quantity varies only 5 per cent. in different months. Over the pole no radiation is received in the long winter night, whereas at the summer solstice, with 24 hr. of daylight, the daily quantity somewhat exceeds that for anywhere else and is actually greatest of all at the South Pole about the December solstice. The amount of energy actually received to heat the earth's surface depends on absorption, reflection, re-radiation and scattering during transmission through the atmosphere, which are particularly affected by cloudiness, and finally depends upon the characteristics of the surface itself. The albedo (reflection coefficient) of snow is very great.

The over-all difference of incident radiation between equator and pole is greatest about the equinoxes, but in the northern hemisphere the greatest meridional contrast of effective heating occurs in winter when the high-albedo snow surface acquires a great extent over the continents outside the region of polar night.

Meteorological data available for study of the Arctic pack-ice region and of the Greenland ice sheet are confined to expedition data starting about 1888–90 with Nansen's expeditions across Greenland and in the s.s. *Fram* drifting in the polar pack. Interpretation[1, 2] is complicated by significant warming of the Arctic, particularly between 1920 and 1938. Only since 1954 have permanent stations been established on the ice, actually by the Russians; interception of their synoptic reports has so far proved difficult. There is a useful network of stations on islands and around the Greenland coast.

The main channel for advection of warm air and warm ocean water and for the escape of drift ice is between Greenland and Norway. High mountains largely insulate the polar basin from the Pacific. Cold air has several preferred outlets.

Depressions penetrate the Arctic most frequently from the Atlantic. The further part of the polar basin is least disturbed. This is where the ice is most permanent and where anticyclonic conditions are relatively frequent. Extremes of surface pressure so far observed over the pack-ice, range from about 960 to 1060 mb.

Over the ice there is nearly always a temperature inversion at the surface or in the lowest 100–200 m. In summer, surface-air temperature is mainly about 0°C. but occasionally rises two or three degrees above, precipitation often falling as rain, leaving pools of water lying about on the ice-floes. In winter the lowest air temperatures reach $-40°$ to $-50°$C. over the pack-ice, $-60°$C. or below in Greenland and Siberia.

Strong winds are rare over the pack-ice in the polar basin; gales occur perhaps once a year near the North Pole.[3] Greenland is most important as a 2,000 to 3,000-m. high barrier in the atmospheric circulation. Other complications are introduced by the very high frequency of a katabatic surface wind system over all the sloping parts of the inland ice and by the strong topographical influences in the coastal strip where the regular observing stations are.

It is impossible to reduce pressures observed at expedition stations on the ice-cap to sea level, because no reasonable temperature can be assigned to the missing air column and because accurate determination of station height is wellnigh impossible. There is a need for the use of 700-mb. charts for tracking winds and weather systems over Greenland.

Antarctica is a continent of estimated area about five and a half to six million square miles, much larger than Europe or Australia, several times larger than the area of permanent ice in the Arctic Ocean and about seven times the size of Greenland. With a probable mean height of 2,500 m., Antarctica is also the most elevated continent in the world. Further, Antarctica must differ from Greenland in having much vaster extents of almost level ice, the high plateau and the shelf-ice near sea level. Another difference in the Antarctic is the absence of oceanic advection of any great meridional currents of warm water equivalent to the Gulf Stream.

Prevailing mean-sea-level pressures in the Antarctic and sub-Antarctic are 20–25 mb. lower than in the corresponding parts of the northern hemisphere. Extreme mean-sea-level pressures so far observed in Antarctica are 927 and 1035 mb. There is no corresponding difference in the intensities of the subtropical, high-pressure systems of northern and southern hemispheres. Thus, the prevailing westerlies of the Southern Ocean are both more prevalent and on average stronger than their northern counterparts.

Former theoretical ideas accorded a permanent existence to the climatological mean pattern of brave west winds, the sub-Antarctic depression belt, polar easterlies and the ice-cap anticyclone. These have proved fallacious. Depressions do occasionally wander on unusual tracks and do sometimes penetrate well south over Antarctica. Two centres below 950 mb. passed south of Admiral Byrd in 80°S. on the Ross Ice Barrier during the 1934 winter. Pressures down to 950 mb. occur over the Southern Ocean even in summer, and centres of 960 mb. occasionally have an extensive central region with light winds.

"Dumb-bell" rotations are common near the fringe of Antarctica, when old decaying depression centres and their occlusions are swung westwards by the circulation around more vigorous cyclonic systems over the ocean to the north. This appears to be specially common in the Ross Sea and the occlusions are liable to pass over the sector of Antarctica between 100 and 170°E. These sequences appear to be the real mechanism of the repeated pressure oscillations

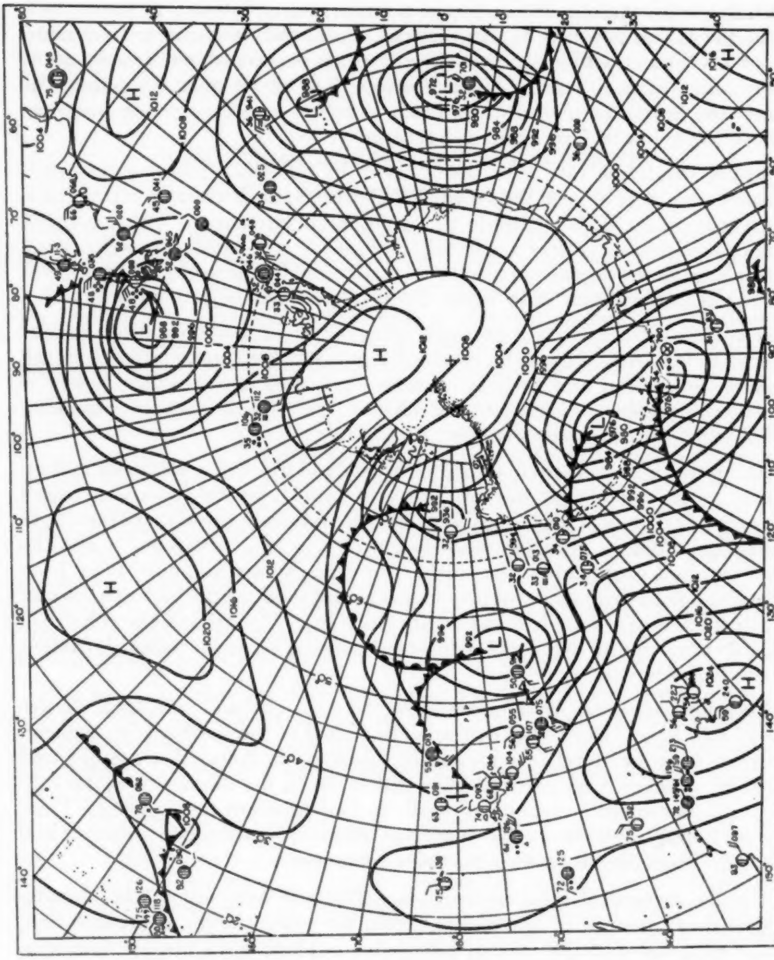


FIG. I—SYNOPTIC CHART FOR 0001 G.M.T., JANUARY 4, 1947

(After the chart in "Naval Weather Service Circular No. 13/51—Synoptic weather sequences for the southern oceans 1946–47" published in 1951.)

passing east to west and north-west across the Ross Sea, which Simpson[4] considered to be surges of a permanent Antarctic anticyclone radiating from the point 80°S., 120°W. Anticyclones are sometimes present over Antarctica for months on end, but at other times there is no room for any anticyclone between the surrounding lows. Occasionally, too, the high is pushed right out over the sea ice; but it is now clear that positions in the heart of east Antarctica near 80°S., 60°E., preponderate.

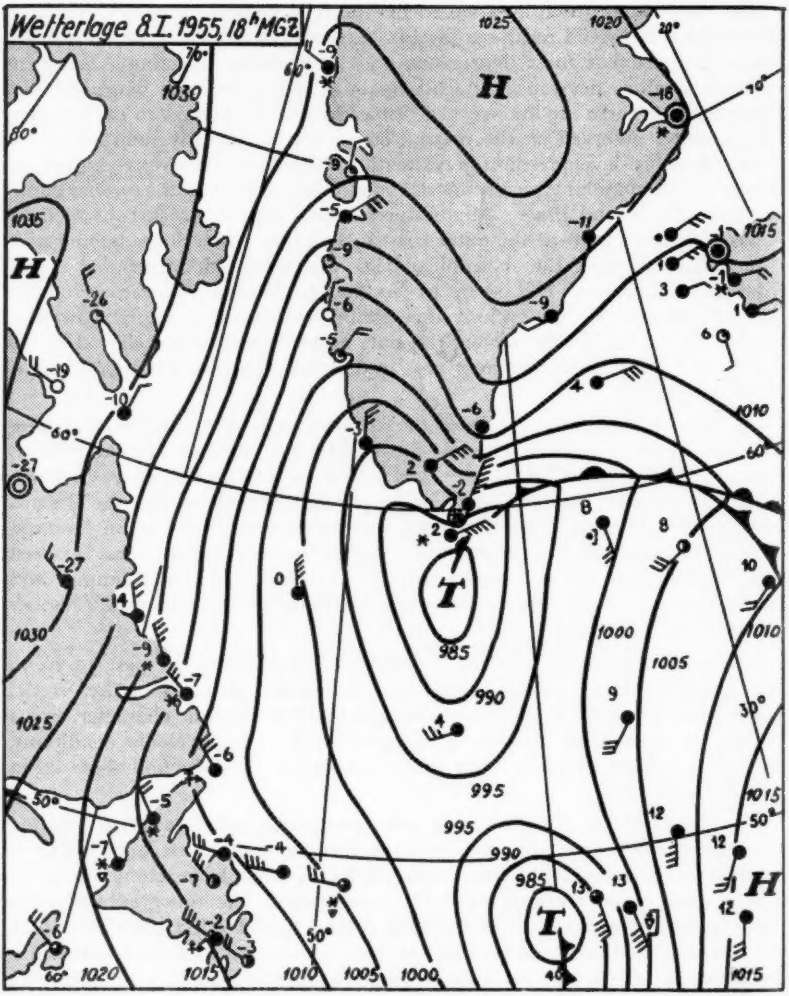
The convention generally adopted in Antarctic analysis as over Greenland at present is to extend mean-sea-level isobars over the ice-cap. There is some justification in that most depressions and anticyclones affecting Antarctica have circulations developed at least up to ice-cap level and winds on the plateau, when these are known, bear some reasonable relation to the isobars; but pressures observed on the plateau could not be formally reduced to sea level. Mean-sea-level pressures in Antarctic anticyclones are never very high, as shown by observations typically about 1000 to 1010 mb. when the systems come out over the coastal bases. All pressures over 1025 mb. so far observed in Antarctica have been at the outer coast in blocking anticyclones temporarily thrusting south from the subtropical belt. Linkages with meridional ridges from the subtropical belt seem to be the mechanism of renewal of the Antarctic continental anticyclone after periods without one. Fig. 1 shows this happening in the Pacific sector, the only sector where it is believed to be common. These pressure waves pass into Antarctica over Simpson's point, 80°S., 120°W.

The seasonal pressure variation in the Ross Sea sector of Antarctica, including the furthest south stations near 80°S., may be described as anti-monsoonal, pressure being highest in summer and lowest in late winter, June–October. This resembles the seasonal trend between south Greenland and the Barents Sea near the Atlantic depression track, where pressures are lowest in January. In the sub-Antarctic and the Antarctic fringe, especially on the coast between Grahamland and 140°E., average pressure has maxima in midsummer and midwinter, but shares the regular and remarkably low minimum of October on the Ross Ice Barrier.

There is no evidence of much climatic variation within the past 50 yr. in the Antarctic, but individual good and bad years occur as in the Arctic. Long spells of given weather type, sometimes of anomalous character, are a feature of both polar regions. Prolonged quiet or anticyclonic conditions, extending beyond the coast, must encourage increased production of sea ice in the sector affected.

The geographical distribution of gale frequencies indicates broad maxima over the open oceans where cyclonic activity is commonest and narrower concentrations associated with intense gales, commonly reaching force 12, where appropriate topographical effects operate[5]. The topographical cases include an important class of so-called frontal funnel effect gales, in which fast moving cold air is constrained to flow in a narrow channel between a mountainous coast and an approaching warm-type front. Such gales can easily be lethal to parties near mountainous sections of the coasts of Greenland and Antarctica; more open exposures, as on the Ross Ice Barrier well away from the mountains, are often safer. Fig. 2 illustrates the effect near Cape Farewell at the south tip of Greenland. Gales and strong winds constitute a greater hazard to expeditions than the low temperatures which can be more easily guarded against. Strong winds in polar environments generally reduce or destroy the surface inversion and raise the surface temperature, though unpleasantly low temperatures can occur with winds of gale force. Blizzards accompany any winds of force 5 or more where loose snow surfaces exist.

Surface-air temperatures in the interior of Antarctica probably fall to extremes of $-60°$ to $-70°$C. in most winters, figures about equal to the



Reproduced by courtesy of Deutscher Wetterdienst Seewetteramt

FIG. 2—"FRONTAL FUNNEL" GALES BETWEEN THE MOUNTAINS OF SOUTH GREENLAND AND AN APPROACHING OCCLUSION

(After Klima und Wetter der Fischereigebiete West-und Südgrönland)

absolute extreme minima in Greenland, the Yukon and north-east Siberia. Maximum summer temperatures in Antarctica are about 0°C. near the coast and −5° to −15°C. at different heights on the inland ice. Points on the coast of Grahamland near open water and where föhn effects operate, as in south-west Greenland, occasionally record +10° to +12°C. at any time of year.

Reproduced by courtesy of R. L. Martin

CUMULONIMBUS MAMMATUS

This photograph was taken at 1830 G.M.T., August 25, 1956, from Hayes, Middlesex. The cloud was over Southall, Middlesex. The evening was one of moderate to heavy showers with local thunderstorms.

Reproduced by courtesy of C. B. Wilberforce

ALTOCUMULUS WITH RIPPLES IN TWO DIRECTIONS AT RIGHT ANGLES

This photograph was taken looking south-west from Harrow at 1830 G.M.T. on September 12, 1956. The cloud was at an estimated height of 12,000 ft. and so far as could be seen the two sets of ripples were at the same height. The 1500 G.M.T. synoptic chart showed a warm front from north to south over western England and a ridge of high pressure over eastern England. It appears likely that the ripples, vertical in the photograph, in a south-west–north-east direction, were formed first as they are broken in places by the other set.

C. B. WILBERFORCE

Although surface inversions are the general rule over the polar ice, there is probably nowhere where an adiabatic lapse rate from the surface up to great heights cannot sometimes be found: such cases appear in 4 per cent. of the available ascents in Arctic and Antarctic. They are probably connected with cold cyclones[6, 7].

Preliminary impressions of the upper westerlies in the southern hemisphere[8] show that there are no such large-amplitude semi-permanent troughs and ridges as in the northern hemisphere. The main trough in latitudes south of 40°S. is in the Indian Ocean sector and the main warm ridge seems to be in the western Pacific where the Antarctic coast is well south of 70°S. Both features appear thermal in origin; they accord with the remarkable glaciation of the islands in 50°–55°S. between Bouvet Island, 3°E., and Heard Island, 73°E. South Georgia, 36°W., is less heavily glaciated. The less hilly Macquarie Island, 54°S., 159°E., loses all its snow in summer. Between Mauritius, 20°S., and Kerguelen, 49°S., in the southern Indian Ocean one finds the whole range of climates from tropical to ice-age. The corresponding belt of upper winds has a mean annual strength of about 50 kt. at 500 mb. and is surely the broadest stream of such strength in the world.

In the northern hemisphere when the zonal index at 500 mb., about 55°N., exceeds 23 kt. over a wide sector the flow generally breaks down into large-amplitude waves leading to stationary blocking patterns. Over the Southern Ocean, in spite of much stronger mean zonal flow any great meridional ridges which form are usually quickly severed by a renewal of the westerlies.

Prof. Gordon Manley wondered if the change in frequency of gales at Jan Mayen could be due to the changed position of the observing station since the war. Mr. Lamb pointed out in reply that the frequency had decreased substantially in the area as far as Spitsbergen where the effects of changes of observing site had been eliminated and this appeared also from the marine data. Prof. Manley then remarked that South Georgia was much more heavily glaciated, with a specially low *firn* line, at its western end than elsewhere: there might be a marked diminution of precipitation from west to east. Heard Island is more uniformly glaciated, and this might be due to its shape being rounder than South Georgia. Mr. Lamb replied that the information about the heavier glaciation of the western end of South Georgia was particularly interesting, because without knowledge of this the difference in glaciation between South Georgia and Heard Island appeared greater than could be fully explained by their relative positions in the zone of strong thermal gradient; however Heard Island is believed to be more or less completely glaciated and the round contour may be chiefly due to the ice. Professor Manley further asked whether the opening up of water channels amongst the Arctic pack-ice could affect the general atmospheric circulation; might there be some critical point beyond which more open water would lead to great changes. Mr. Lamb thought that the heat exchange between the atmosphere and the Arctic Ocean would show a continuous, gradual change if the amount of open water amongst the ice were increased.

Mr. A. Elliot asked about the strength of the katabatic winds over Greenland and how they modified the general flow of the atmosphere. Mr. Hamilton replied that katabatic flow was dominant over most of the inland ice, its persistence and strength increased where the downward slope of the ice

increased and in certain coastal fjords and valleys the funnelling of this katabatic flow produced violent gales, sometimes exceeding 100 kt. These gales were often characteristically localized; in side valleys only a short distance out of the main channel only light airs might be found. There were also occasional lulls at points in the main path of the gale when intervals of complete calm or a light contrary breeze might be experienced.

Mr. Peters interposed to direct attention to Mr. H. H. Lamb's work in 1936–39[9] on synoptic analysis over Greenland and the interpretation of observations reported by the coastal stations. These stations were still operating in 1956.

Dr. Stagg took up the question of the spasmodic nature of the katabatic winds off ice-caps and referred to Hobbs's theory of the permanent glacial anticyclone. Hobbs considered that pressure gradually built up in an accumulating reservoir of cold air over the ice-cap till it could be held no longer; the cold air then rushed out with gale force, followed by a period of comparative calm in which the skin of cold air built up again. These successive pulses of activity were given the name of "strophs" of the anticyclone. In more recent years, as observations around the coastal fringe became more plentiful, Hobbs seemed to have become discredited. We were now told of depressions going straight across Greenland. Could this be really right? In what sense could a depression pass right across Greenland? Mr. Lamb replied that Hobbs's theory really was regarded as exploded nowadays, because the idea of a permanent anticyclone over the inland ice was in direct conflict with the observations. Nansen, on his first crossing of Greenland in 1888, had sixteen days with normal snowfall out of forty days spent on the ice. The Wegener expedition's Eismitte station near 71°N. 40°W., manned by Georgii from August 1930 to August 1931, showed frequent long, stormy periods, usually with snow and strong winds from between SE. and SSW., whereas the briefer periods of good weather came usually with light winds from between NW. and NE. At Eismitte, where the slope of the ice plateau, nearly 3,000 m. above sea level, is almost imperceptible, the katabatic wind only occurred intermittently when fine weather permitted[2, 10, 11]. Of course, only the upper part of a depression can pass more or less unchanged over a barrier of this height; the circulation in the lower levels must be re-developed in the air masses on the further side. Very many depressions are held up in the Davis Strait and Baffin Bay and fail to pass Greenland; nevertheless the associated warm sectors generally continue east over the Atlantic and commonly a new low develops south-east of Greenland in association with these fronts. Mr. Hamilton added that in cases where the occlusion passed right across Greenland he had found that 700-mb. charts explained very well the sequence of wind veers and snowfall over the ice plateau. In north-east Greenland a front was commonly preceded by light south-easterly breezes; the katabatic wind returned abruptly as the front passed.

Prof. Manley remarked on an authenticated case in which a depression crossing northern Greenland in July gave rain on the ice cap at 8,000 ft.

Mr. Lamb added that the manner in which many depressions cross Greenland, following situations originally dominated on the east side by a north-east Greenland anticyclone, has been well described in a useful study of Greenland

by Rodewald[12]. Often a sustained fall of pressure sets in, even in the region of northerly winds east of the Greenland ridge and a new depression soon dominates the situation east of Greenland.

Mr. McNaughton said that, as in the case of Greenland, depressions from the west sometimes passed across Grahamland, leaving a residual centre west of the peninsula. Alternatively new centres developed east of Grahamland. Similar sequences occurred across South America.

Mr. Peters asked Mr. Hamilton about adequacy of data for his 700-mb. analyses over Greenland. Mr. Hamilton pointed to the radio-sonde stations in the Canadian Arctic to 82°N. and all around the fringe of Greenland: the rest depended upon tracking the fronts across Greenland from their passage over stations in the south-west until they turned up at the British North Greenland Expeditition's ice-cap station, Northice.

Mr. Harding regretted the sparseness of the network of upper air observations in the Pacific sector of the Southern Ocean and Antarctica, even in the network proposed for the International Geophysical Year. Long distance flights have already been undertaken by American aircraft from New Zealand to the Antarctic. Royal Air Force or British civil aircraft which might be employed in the future on similar flights would probably fly at great heights, possibly as high as 50,000 ft. Reliable mapping of the belt of particularly strong upper westerlies over the Southern Ocean would be vital to the safety of such flights.

Finally, Mr. Lamb showed a dozen lantern slides illustrating typical synoptic situations over the Arctic and Antarctic.

Dr. Farquharson asked about the adequacy of the observational coverage in the southern hemisphere for hemispherical surface analyses of the type shown. This is an important question, deserving more consideration than could be given in a few minutes at the end of the meeting. Upon the adequacy of the network, especially over the Southern Ocean, depends the validity of interpretations which it may be possible to derive from the synoptic work undertaken in Antarctica during the International Geophysical Year. The network between 40° and 65°S. is for the most part limited to eight or ten island observing stations broadly spaced between 60°W. and 170°E. plus stations in the Grahamland peninsula, Tasmania and New Zealand, and an average of about ten ships a day. The shipping is largely confined to whaling fleets and expedition ships operating during the summer half-year, November–April. This network is far sparser than over the North Atlantic, but there are indications that it is sufficient to settle the main features of the general circulation over the Southern Ocean (see, for instance,[13, 14]). In Mr. Lamb's opinion the only gap in the network which is often unbridgeable is in the South Pacific, especially between latitudes 35° and 70°S. In all sectors, however, it is noticeable that the statistical indications of the various available series of daily synoptic analyses which have been attempted[14, 15, 16, 17, 18] in terms of the geographical distribution of anticyclone and depression populations have confirmed each other in considerable detail as the observation network has improved; most of the island stations in the Southern Ocean have been opened since the earliest chart series referred to. Their observations have made synoptic analysis easier and more precise, but have not changed the general picture.

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ACCURACY OF GEOSTROPHIC TRAJECTORIES

By C. S. DURST, B.A. and N. E. DAVIS, M.A.

Since the following of air tracks by geostrophic trajectories is frequently practised and in some cases the trajectories are pursued for long periods, it is perhaps well that these notes should be published, which give the degree of inaccuracy to which geostrophic trajectories are subject owing to the failure of the measured geostrophic wind to represent truly the path of individual air particles.

The accuracy of measurement of wind from isobars.—In a paper on convergence and divergence in the atmosphere[1], estimates have been made of

(i) the magnitude of the ageostrophic wind, and

(ii) the magnitude of the error that is likely to be made in measuring a pressure gradient.

These magnitudes were obtained for a height of about 1,500 ft. over south-east England. At that height in that locality the ageostrophic winds are

probably on the high side and the errors in measurement are certainly far lower than at greater heights and in less accurately surveyed areas.

The root-mean-square value of the ageostrophic wind in January 1938 was about 9 kt., and thus, taking account that the ageostrophic wind is probably less in summer and possibly less at higher levels, we may expect the probable value of the ageostrophic wind during the year as a whole to be of the order of 5 kt.; a magnitude of 10 kt. was found by Bannon[2] for the ageostrophic winds at 10,000 ft., so we can say that 5 kt. is a conservative estimate*. We may, moreover, expect that the average duration of such ageostrophic winds is 6 hr. in view of their being usually associated with the passage of depressions and fronts.

The probable error in measurement of the geostrophic wind was found to be 2 miles/hr. along and across the isobars, i.e. a probable vector error of about 2½ kt. This will certainly rise to 3 or 4 kt. at greater heights and may well be 10 kt. or more over the less well known areas of the globe. On the average let us assume an error of 5 kt. in the measurement of the geostrophic wind. (Murray[3] found errors of 5, 7, 8 and 6 kt. at 700 mb., 500 mb., 300 mb. and 200 mb. respectively.)

The departure of the geostrophic trajectory from the true trajectory.—Combining the two we can assume that the vector error involved in assuming the geostrophic wind to be the true wind is of the order of 7 kt. This means that in 6 hr. the end of the geostrophic trajectory is likely to be 40 nautical miles away from the true position of the air parcel to which it is supposed to refer.

It is reasonable to suppose that the departures will increase as the square root of the duration of the trajectory, and on this basis we get in Table I the probable departures from true position of the ends of the geostrophic trajectories after different intervals of time.

TABLE I—ESTIMATED DEPARTURES FROM TRUE POSITION OF ENDS OF GEOSTROPHIC TRAJECTORIES AFTER SPECIFIED TIMES

Time	6 hr.	24 hr.	2 days	4 days	8 days
Probable departure			*miles*		
	50	100	130	200	260

The dispersion of air masses due to eddies.—It is well known through the work of Richardson[4] and others that two parcels of air initially near together will drift apart owing to the operation of the eddies. This effect was investigated by tracking air from 4 points over the British Isles and measuring their distance apart after 6, 12, 18, 24, 30 and 36 hr. The points chosen were London, and points 50, 150 and 350 miles due north of London and the tracks were followed at a height of 700 mb. during the month of February 1948, one set of tracks beginning at midnight each day for a period of 20 days. The results are shown in Table II.

*This may be compared with estimates of the mean-square ageostrophic wind by Murray[3] He gives values of 6 kt. at 700 mb., 9 kt. at 500 mb., 13 kt. at 300 mb. and 8 kt. at 200 mb.

TABLE II—MEAN DISTANCE $\bar{l}$ MILES APART AFTER A TIME t HR. OF PAIRS OF PARCELS INITIALLY AT A DISTANCE OF l_0 MILES

l_0	t 6 hr.	12 hr.	18 hr.	24 hr.	30 hr.	36 hr.
miles	*miles*					
50	74	118	131	148	169	200
100	138	159	220	279	313	332
150	198	259	319	391	439	484
200	255	320	397	484	581	653
300	371	428	589	729	837	926
350	438	549	671	820	956	1070

If we consider the relation between $\bar{l}-l_0$ and t for each l_0 we find a linear regression of the form

$$\bar{l}-l_0 = A(l_0).t$$

with highly significant correlations $\geqslant 0{\cdot}99$ (see Fig. 1). Further, if we consider the relation between l_0 and $A(l_0)$ we find a linear regression between $\log l_0$ and $\log A(l_0)$ with highly significant correlation $> 0{\cdot}995$ (see Fig. 2) leading to the relation

$$A(l_0) = 0{\cdot}13 l_0^{0{\cdot}86}.$$

Hence the dispersion of pairs of parcels is carried out according to the law

$$\bar{l}-l_0 = 0{\cdot}13 l_0^{0{\cdot}86}.t.$$

Table III uses this relation.

TABLE III—MEAN DISTANCE APART AFTER t' DAYS OF TWO PARCELS INITIALLY l_0 MILES APART

l_0	t' 1 day	2 days	3 days	4 days	5 days	6 days	7 days	Increase per day
miles	*miles*							
50	143	236	328	421	514	607	700	+ 97
100	268	437	605	774	942	1111	1279	+168
200	506	812	1117	1423	1729	2035	2341	+306
300	733	1167	1600	2033	2467	2900	3334	+433

The magnitude of the errors in plotted trajectories.—The figures given in Tables I and III may be looked on in this way. The inherent inaccuracy of geostrophic trajectories will lead to a small departure of the plotted trajectory from the true trajectory. This departure will be enhanced rapidly by the eddy effect and one can surmise that the order of departure of the plotted trajectory from the true after a week will be 1,000 miles, after 10 days 2,000 miles, and after a fortnight 3,000 miles. It must moreover be remembered that these values are the radii of the 50 per cent. circles, and on half the occasions the errors will be greater.

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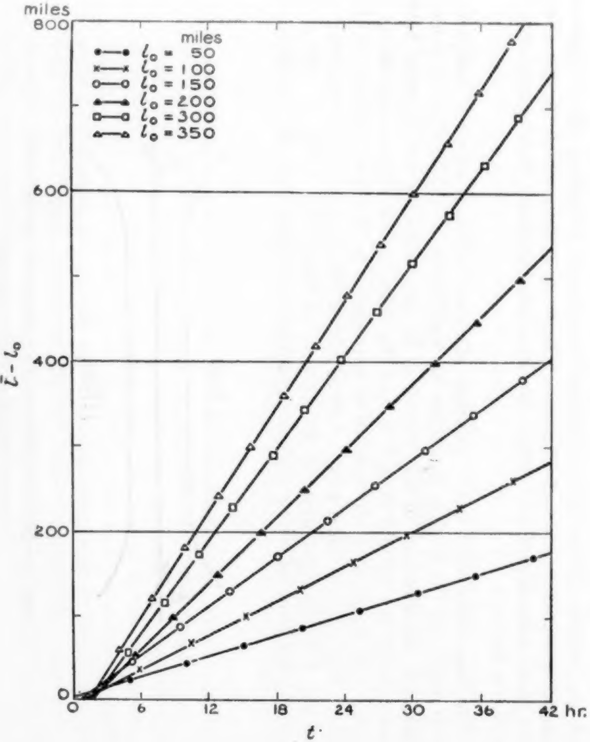

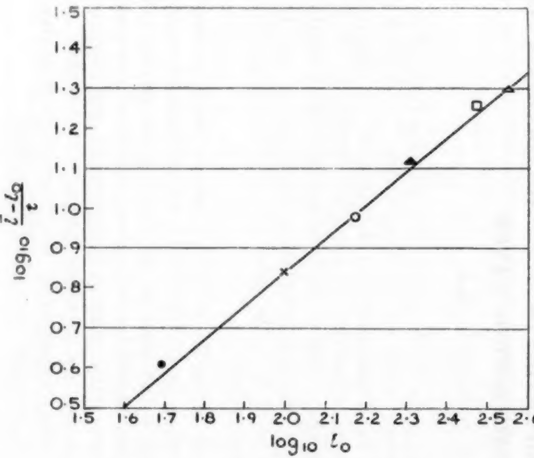

FIG. 2—RELATION BETWEEN SLOPE OF REGRESSION $(\bar{l}-l_0)/t$ AND l_0

FIG. 1 (*left*)—RELATION BETWEEN TIME AND INCREASE OF DISTANCE APART OF PAIRS OF PARCELS OF AIR FOR VARIOUS INITIAL DISTANCES

SOME INTERESTING PROPERTIES OF THE "NULLSCHICHT" OR MAXIMUM-WIND LAYER

By H. H. LAMB, M.A.

British meteorologists may like to be made aware of a growing body of work in the German literature of recent years on the "Nullschicht"[1-7]. This is the name adopted in German by Faust and others for that level in the uppermost part of the troposphere where the mean vertical motion is approximately zero —hence "zero layer" (Nullschicht). This is the level towards which resultant tropospheric and stratospheric vertical circulation components are both directed in deep depressions, and it is the level of corresponding vertical divergence in high reaching anticyclones.

Statistical comparisons of the generality of cases over two years in central Europe show that the mean level of the "Nullschicht", which is found at about 10 Km. above mean sea level, is the same as the level of maximum wind. Moreover, it is logical that this should be so in most individual cases also: below the "Nullschicht" upward motion prevails in depressions and downward motion in anticyclones; depressions are therefore normally colder than anticyclones at all heights up to this; consequently the thermal gradient should produce the maximum wind at, or quite near, the "Nullschicht."

Small discrepancies of height between the two levels may arise, partly because the "Nullschicht" itself tends to be a little higher in anticyclones than in depressions,moving up and down with about half the amplitude of the corresponding changes of level of the tropopause. Also localized vertical motions are to be found in the "Nullschicht", where it is penetrated by convection cells and by various forms of mechanical turbulence including the important clear-air turbulence near jet streams[8]. These are details which do not affect the proper definition of the layer as one in which the mean broad-scale vertical motion is zero.

The maximum-wind layer—perhaps the more obvious name to adopt for it—is inevitably the level at which the air is subjected to the strongest accelerations and decelerations in the course of its flow through the pressure field; consequently one should expect to find the strongest developmental effects of inertia and changes of momentum to correspond to the flow patterns in this layer. The simplest ideal cases of these inertia effects arise at the entrance to and exit from straight westerly jet streams, as illustrated in Fig. 1. Air at A entering the zone of strong pressure gradient associated with the jet stream is

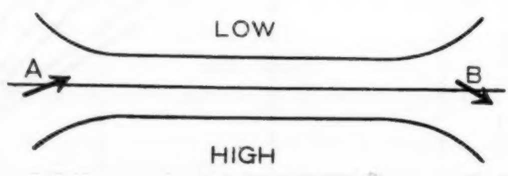

FIG. 1—INERTIA EFFECTS AT ENTRANCE TO AND EXIT FROM WESTERLY JET STREAM

moving too slowly for the increased pressure gradient and, as in the case of air in the surface friction layer, is deflected towards the low-pressure side (deflexion exaggerated in diagram). Usually there is some lateral shear between air entering the jet and slower moving air on either side, which undergoes less acceleration. The ageostrophic deflexion of air at A therefore gives rise to convergence and rising pressure at the left of the entrance to the jet (in the sense of the wind stream) and to divergence and falling pressure at the right of the entrance. Air at the jet exit, leaving the zone of strongest pressure gradient, is moving too fast for balance with the actual pressure gradient at B and experiences a deflexion towards the higher pressure side: given the required lateral shear, this effect should give rising pressure at the right and falling pressure at the left of the delta of the jet. The reality of occurrence of these ageostrophic motions at jet-stream level has been demonstrated by Murray and Daniels[9].

The maximum-wind level would deserve special attention for these inertia effects alone. Interest in the "Nullschicht" has grown further however as other, more unexpected, properties of this layer have come to light. These properties relate to the layer as a whole and not just to the jet streams within it.

In a number of carefully devised statistical approaches, making use, *inter alia*, of the interdiurnal (day-to-day) temperature changes observed in moving air parcels at many different levels in order to detect the exact height ranges within which general vertical motion goes on and in a considerable variety of defined situations, Faust has discovered:

(i) In cases where there is a well defined maximum in the vertical distribution of horizontal wind speed—i.e. cases of strong vertical shear above and below the strongest winds in the air column—the maximum wind is above gradient strength both on average and in a considerable majority of the individual cases measurable. This appears to hold true whether the maximum wind is at 225 or 500 mb. in the material examined (or any other level in the upper troposphere). In cases where the maximum winds over Germany were at 225 mb. and exceeded twice the strength of the winds at 175 and 275 mb., the 225-mb. wind was on average 10 per cent. above gradient strength and in nearly one case in six over 50 per cent. above gradient strength. (Scherhag[10] has reported a mean excess of actual wind over gradient wind of 1·6 kt. in the layers between 500 and 225 mb. which commonly contain the maximum wind.) Further tests removed all ground for supposing that these systematic departures could be just a result of the difficulty of drawing the contours or isobars in cases of strong winds.

(ii) In cases of a well defined level of maximum wind, there is on average an ageostrophic flow towards higher pressure in the maximum-wind level. This was confirmed by statistical studies both of 24-hr. thickness changes and of pressure changes at the surface and in the upper troposphere. (Reineke[11] found a mean deviation of actual wind from gradient-wind direction of 7° towards the higher pressure side between the 500- and 225-mb. levels. A recent paper[12] has confirmed the existence on average of a maximum ageostrophic wind over England at about 300 mb. with a component directed towards higher pressure.)

(iii) The "Nullschicht" effects noted in (i) and (ii) are found to be quasi-proportional to the speed of the maximum wind and to the magnitude of the vertical shear above and below the maximum-wind level.

(iv) The tropopause is found on average about 1 Km. above the maximum-wind level. Sorting of cases reveals an average tropopause height of 2 Km. above the maximum winds in anticyclones and at the south side of jet streams, and an average of less than 0·5 Km. above the maximum-wind level in depressions and at the north side of jet streams in 55°N. Geographical distribution showed the tropopause on average 1·3 Km. above the "Nullschicht" in 40°N. and just 0·5 Km. above in 70°N.; since, however, the change in the vertical distance between the levels of tropopause and maximum wind on either side of the jet stream is greater than the normal difference between 40° and 70°N., the events near the jet stream must be at least partly attributable to vertical motion and not purely due to advection from either side. Faust suggests that the main height variations of the tropopause are themselves to be attributed to the upward and downward "pumping", corresponding to vertical divergence and convergence, associated with the "Nullschicht" phenomena, including those brought about by inertia and momentum changes in and near the level of maximum wind.

(v) In cases where there is no sharp upper-wind maximum, there tends to be an ageostrophic flow from higher towards lower pressure even at the levels where the strongest winds exist.

The empirically discovered "Nullschicht" phenomena are by no means all readily amenable as yet to theoretical explanation. Nevertheless there is a logical necessity for the normal existence of over gradient winds in various upper levels, to compensate the continual flow from high to low pressure associated with under gradient winds in the layers affected by surface friction. Otherwise no pressure differences could be maintained, far less strong circulations be built up.

It is much less easy to suggest how a mean excess over gradient-wind strength can in fact arise in the free atmosphere. Hollmann's suggestion is that kinetic energy is built up close underneath the tropopause because convection mixing may be found to carry more energy upwards in the strong-wind regions in depressions than is transported downwards in anticyclones, where the pressure gradients are weaker and convection is discouraged by more stable stratification.

The maximum-wind layer and the layers near the ground must be thought of as the loci of maxima of ageostrophic motion in the horizontal wind field. Since the departures from gradient wind are in opposite senses in the upper and lower troposphere, one would expect to find some intermediate level at which the actual winds came close to the gradient wind. This theoretical level of non-divergence or equivalent barotropic level has been commonly assumed to be about 600 mb. A recent investigation[13] however suggests that in reality no level of strict non-divergence exists: the points in the atmosphere at which horizontal divergence is at a minimum tend to arrange themselves on coherent quasi-horizontal surfaces recognizable as continuous over limited areas and periods of time; their height is actually between 6,000 and 10,000 ft. in most cases.

Faust's measurements[2], from which the discoveries here listed emerged, were largely made outside the actual jet streams, for various reasons associated with amenability to reliable and, where possible, accurate measurement. He quotes Murray and Daniels'[9] figures from measurements made near the midway point of the length of straight jet streams, where no confluence or diffluence effects could be working, as providing confirmation of a net ageostrophic flow from lower to higher pressure within the jet-stream systems themselves.

A further point to note is that Faust's "Nullschicht" effect, normal ageostrophic flow towards higher pressure, works against the developmental pattern of the confluence (point A on the diagram, Fig. 1) and tends to strengthen the developmental pattern of the deltas.

In a statistical study of rainfall amounts and frequencies in relation to straight jet streams at four British and Irish stations over a 3-yr. period, with care taken to eliminate local effects, Johnson and Daniels[14] found rain maxima at the right of the entrance and left of the exit of the jet. This distribution agrees with the distribution of net vertical components of air circulation to be expected from inertia effects, as illustrated in our diagram. It is interesting to note that the rain distribution was more definite at the jet exit than at the entrance, as the "Nullschicht" effect would suggest. The rain-distribution data were however inadequate to decide whether there was any preferred vertical motion near the middle of the jet stream.

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STANDING WAVES IN THE VALE OF YORK

By F. P. U. CROKER

Ground observations at Dishforth and air observations over the Vale of York suggest that on December 5 and 6, 1955, a system of standing waves lay over the area. It is thought that this system may have extended along the line parallel to and in the lee of the Pennines, but information outside the Dishforth area is lacking. It may be of interest to describe briefly the circumstances, since these corroborate the conclusions reached by Pilsbury about the conditions required for the formation of standing waves[1]. Moreover, the liability of airfields to be affected by a standing-wave system carries implications which, it is felt, may justify further study.

At 1500 G.M.T. on December 5 pressure was high to the south and low to the north of the British Isles. A warm front had recently cleared Dishforth and was moving rapidly away eastward. A cold front lay east and west across Scotland. This moved slowly south but paused in about 57°N. latitude on December 6 while a wave depression moved quickly along it from west to east across Scotland. The strong westerly gradient wind over northern England increased during the night of December 5–6 but eased again the following day. Dry-bulb temperature curves and upper winds from the Liverpool radio-sonde ascents from 1400 G.M.T., December 5 to 1400 G.M.T., December 6, inclusive, are reproduced in Fig. 1. It will be seen that the first two ascents show a steep lapse rate to about 5,000 ft. followed by a marked inversion. Wind directions are fairly constant up to 700 mb., well above the top of the inversion; wind speeds are well over 20 kt. and increase with height. These are precisely the conditions formulated by Pilsbury for standing-wave development. The third ascent shows the inversion in the process of breaking down and an evening out in the wind-velocity profile with height.

Pilots flying on the night of December 5–6 state that they experienced strong and prolonged up-and-down draughts in addition to turbulence. One instructor flying in the approaches to Topcliffe, five miles north of Dishforth, between 2000 and 2200 G.M.T. approximately, states that in the area there were constant up-draughts during the first hour of a strength which caused him to throttle back his engines and maintain a shallow dive in order to avoid gaining height. After a slack interval, the up-draughts were replaced during the second hour by down-draughts of sufficient strength to make it necessary for him to climb on full power in order to maintain height. These down-draughts, unlike the up-draughts, were accompanied by heavy turbulence. Similar conditions were experienced the following day, but of lesser intensity. They seem to have died out at some time during the afternoon, i.e. during the time when the upper air conditions were changing. One pilot flying during the morning of December 6 states that the lower cloud displayed a wave-like appearance, the distance between wave crests being estimated at 15 miles.

At 1300 G.M.T. on December 6, the surface wind at Dishforth, which had been blowing fairly consistently from the south-west at some 15 kt., began to ease and eventually, at 1500 G.M.T., the pointer of the wind-direction indicator in the Meteorological Office began to rotate; a somewhat disconcerting event in view of the gradient wind of some 35 kt. Immediate steps were taken to check the veracity of the reading and it was confirmed by Air Traffic Control, near which the anemometer is sited, that the wind vane itself was rotating and that

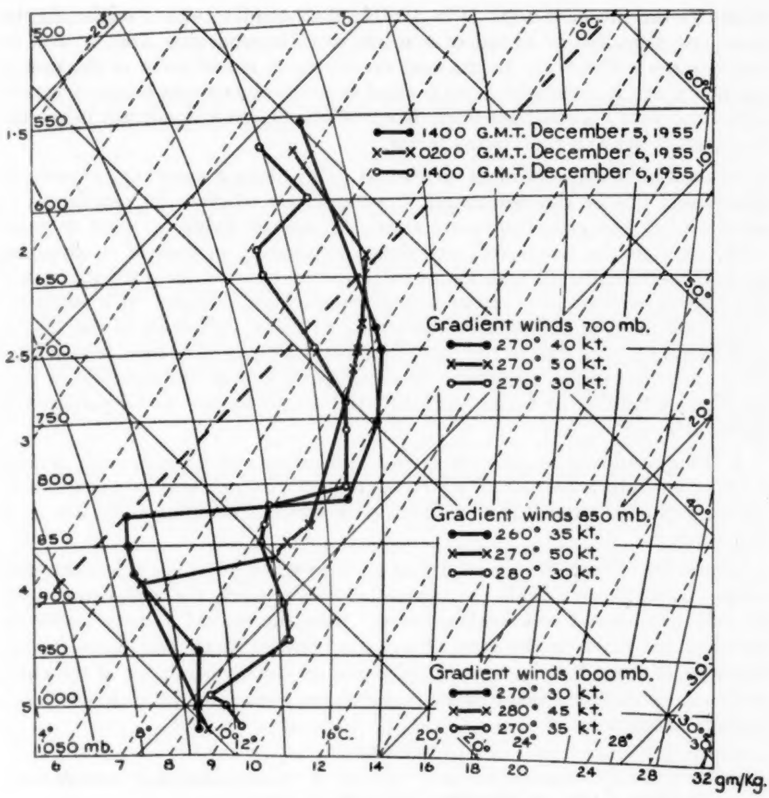

FIG. 1—DRY-BULB TEMPERATURE CURVES AND UPPER WINDS FROM LIVERPOOL RADIO-SONDE ASCENTS DECEMBER 5–6, 1955

there were no disturbing influences in the vicinity, such as aircraft running up their engines, which might account for its behaviour. By 1530 G.M.T. the surface wind had recovered its former velocity and, in fact, showed a tendency to increase. It will be appreciated that this phenomenon, also, occurred about the time that the upper air conditions were changing and could reasonably be connected with the collapse of the wave system, or, perhaps, an alteration in the position of a wave in relation to Dishforth, for, while strong surface winds are expected under a wave trough, those under a wave crest should be lighter.

As far as Dishforth and other airfields in the lee of the Pennines are concerned it would seem that for the formation of standing waves a synoptic situation is required of the same general nature as that existing on December 5 and 6, with an anticyclone to the south but close enough to provide a subsidence inversion, and low pressure to the north, giving, in conjunction with the anticyclone, a vigorous westerly air stream, reasonably constant in direction to the

height of the inversion top. It is possible that standing waves might also be produced immediately ahead of a warm front approaching from a west or north-westerly direction. In this case the inversion would occur at the frontal boundary and it is thought that the wind veer with increasing height normally associated with approaching warm fronts might be too insignificant below the inversion to act as a prohibiting factor.

In standing-wave conditions an aircraft flying along a wave may experience continuous up- or down-draughts, depending on whether its position is to windward or leeward of the wave crest. An aircraft flying up wind or down wind through the waves will experience alternating periods of up-draughts and down-draughts. In addition, it will encounter variations in the strength of the horizontal wind as it passes successive crests and troughs. It is suggested that these may be sufficient in themselves to cause variations in the lift. It will be appreciated that in the case of an aircraft flying at or near trough level such variations would aggravate the effect of the up- or down-draughts, thus an aircraft landing or taking off into wind would appear to be particularly vulnerable.

It is for consideration whether or not such effects can be sufficiently powerful to constitute a hazard to air navigation in general, and in particular to the operation of aircraft from airfields over which a standing-wave system is in existence.

It may be of interest to record that on September 12, 1956, when standing wave conditions were again present in the Vale of York, the author was taken in a Pioneer aircraft to investigate them. Near the airfield and level with the cloud plume marking the crest of a wave between 5,000 and 6,000 ft., up-draughts of 1,000 ft./min. were encountered on the up wind side of the cloud and down-draughts of 800 ft./min. on the down wind side of the cloud. There was no turbulence.

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[The variation in the horizontal wind can, on Scorer's theory, be of the order of 10–20 kt. The horizontal component of wind due to the wave motion is given by $u = -\partial(U\zeta)/\partial z$ in which U is the basic wind and ζ the vertical displacement of a stream-line from its mean position. If the variation of U with height is neglected u is given by $-U\partial\zeta/\partial z$ which shows that if ζ is increasing with height, as it is up to the inversion, u is negative below crests and positive below troughs so that below the inversion the troughs are regions of increased wind. Above the inversion where the amplitude decreases with height the situation is reversed.—Ed., *M.M.*]

WINTER TEMPERATURES IN LONG AND SHORT GRASS

By M. J. T. NORMAN, Ph.D., Mrs. A. W. KEMP, B.Sc. and Mrs. J. E. TAYLER, B.Sc.
(The Grassland Research Institute, Hurley, Berkshire)

At the Grassland Research Institute, Hurley, the effect of microclimate upon the growth and death of herbage in winter and early spring is being studied. As part of the investigation, continuous records of temperature at 1 in. above soil level were obtained during two winters on two types of sward.

The swards were:

(i) long herbage, 12–18 in. tall, uncut throughout the preceding growing season

(ii) short herbage, 1 in. tall, cut frequently in early autumn prior to the recording of temperature.

The two sites at which temperatures were recorded lay within 5 yd. of each other, in permanent pasture on the slope of a chalk escarpment facing north-north-west and overlooking the Thames valley. The sites were 200 ft. above mean sea level and 100 ft. above the valley floor. Conditions were not conducive to the local ponding of cold air at night.

Temperatures were measured with mercury-in-steel thermographs. The bulbs were 6·5 in. long and 0·75 in. in diameter, shielded from direct radiation by half cylinders of "white acetate" plastic 9 in. long and 2 in. in diameter. Records were obtained during 1953–54 from November 4 to March 23, and during 1954–55 from November 8 to March 13. On account of the failure of a thermograph clock, records for the week January 10–16 were incomplete and were not included in the data. For convenience, the two series of records were divided into periods, normally of four-weeks duration (Table I).

TABLE I—PERIODS DURING WHICH RECORDS WERE OBTAINED

Period	1953–1954	Period	1954–1955
A	November 4–December 1	F	November 8–December 7
B	December 2–December 29	G	December 8–January 8
C	December 30–January 26	H	January 17–February 13
D	January 27–February 23	I	February 14–March 13
E	February 24–March 23		

Table II shows the period means and aggregates of certain temperature characteristics. Accumulated temperatures were computed directly from the thermograph traces by measurement of area above or below the trace to the chosen base line. Mean temperatures were derived from values read at every 2-hr. division on the trace.

TABLE II—TEMPERATURE CHARACTERISTICS IN LONG AND SHORT GRASS

Period	Mean daily temperature (°F.)		Mean daily maximum (°F.)		Mean daily minimum (°F.)		Accumulated temperature above 42°F. (day–°F.)		Accumulated temperature below 32°F. (day–°F.)		No. of frosts (min. < 32°F.)*	
	Short grass	Long grass	Short grass	Long grass	Short grass	Long grass	Short grass	Long grass	Short grass	Long grass	Short grass	Long grass
A	43·0	44·8	49·4	47·7	38·0	41·9	78·2	89·2	1·2	...	3	...
B	42·1	44·0	46·3	46·1	38·1	41·9	58·5	80·1	1·8	...	6	...
C	34·2	36·2	40·2	39·6	29·8	33·5	19·1	13·9	45·3	10·4	20	11
D	30·6	32·1	40·3	35·4	25·4	29·8	8·2	1·8	105·2	60·0	20	18
E	39·2	38·6	51·7	43·4	32·6	35·4	56·2	21·3	11·8	0·9	13	7
1953–54	37·8	39·1	45·6	42·4	32·8	36·5	220·2	206·3	165·3	71·3	62	36
F	41·8	42·4	47·4	46·4	36·6	38·5	61·0	50·8	0·5	...	4	...
G	38·6	39·0	42·4	41·5	35·1	36·8	47·0	32·1	9·4	3·0	15	4
H	36·8	36·5	42·4	39·4	31·9	33·9	23·9	21·9	32·6	14·5	15	10
I	31·1	31·1	37·8	34·9	26·7	29·5	2·0	...	62·4	34·9	26	27
1954–55	37·1	37·5	42·5	40·6	32·6	34·6	133·9	104·8	104·9	52·4	60	41

[*Note.—This definition is not in agreement with meteorological terminology in which "ground frost" is applied to occasions of temperature 30·4°F. and below.—Ed., *M.M.*]

In 1953–54, mean temperature in long herbage exceeded that in short herbage by 1·3°F. This was due almost entirely to differences in night temperature. However, though day temperatures in the two swards were similar, the maximum was 3·2°F. higher in short herbage and the minimum 3·7°F. lower. In 1954–55, temperature contrasts between the two swards were smaller. Maxima differed by only 1·9°F. and minima by 2·0°F., while mean temperatures were close to each other.

The aggregate effect of the difference in herbage cover upon growing and killing conditions may be approximately estimated by comparing accumulated temperatures. In 1953–54, accumulated temperatures above 42°F. differed little, but accumulated temperatures below 32°F. were more than twice as great in short herbage. Values below 32°F. in 1954–55 showed a similar relationship, but values above 42°F. in short herbage were about 28 per cent greater than those in long herbage. Frosts were recorded more frequently in the short sward; there were 26 additional frosts in 1953–54 and 19 in 1954–55.

Night temperatures in short and long herbage (t_s and t_l respectively) were of further interest. Good correlations were obtained between individual values of the general night temperature, expressed here as the mean of night temperature in the two swards, $(t_s + t_l)/2 = m$, and the difference between them, $t_l - t_s = d$, when the comparison was made over a relatively short time. The correlation coefficients between m and d for the nine periods are given in Table III.

TABLE III—CORRELATION COEFFICIENTS FOR m AND d

Period	Correlation coefficient	Period	Correlation coefficient
A	−0·93	F	−0·83
B	−0·81	G	−0·82
C	−0·74	H	−0·85
D	−0·86	I	−0·89
E	−0·85		

Thus, on cool nights, temperatures in the short sward were well below those in the long sward. As the general night temperature rose, differences between the two swards became smaller. On very warm nights, temperatures were frequently a little higher in the short herbage. Some extreme values are given in Table IV.

TABLE IV—SOME EXTREME TEMPERATURES

	Short herbage	Long herbage		Short herbage	Long herbage
	°F.	°F.		°F.	°F.
November 8, 1953	50·5	49·4	January 31, 1954	17·1	25·3
December 2, 1954	52·3	50·8	January 19, 1955	20·6	27·5

However, the general night temperature at which a particular difference could be expected varied between periods and between years at the corresponding period. Examples are shown in Table V.

TABLE V—HIGHEST GENERAL TEMPERATURE m AT WHICH A DIFFERENCE d OF MORE THAN 2°F. COULD BE EXPECTED

Period	°F.	Period	°F.
A	44	F	38
B	44	G	33
C	36	H	32
D	31	I	29
E	35		

These relationships are expressed graphically in Figs. 1 and 2. In constructing these graphs, individual values of general night temperature, m, were grouped within each period into 5° classes. Differences in night temperature, d, between the two swards were then plotted period by period for each class. The points vary considerably in accuracy in accordance with the number of observations they represent.

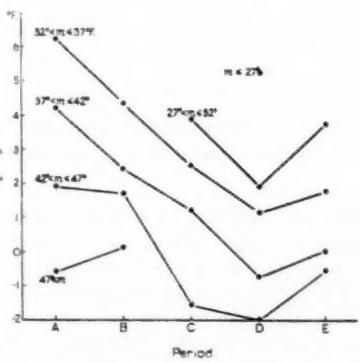

FIG. 1—NIGHT TEMPERATURES IN SHORT AND LONG GRASS, WINTER 1953–54

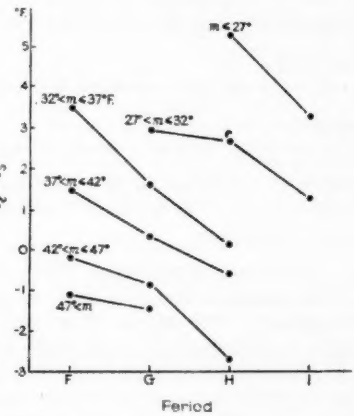

FIG. 2—NIGHT TEMPERATURES IN SHORT AND LONG GRASS, WINTER 1954–55

The clear separation of the lines for each class reflects the relationship indicated by the correlation coefficients. The approximate parallelism of the lines suggests a constant rate of change of d with respect to m over the period of recording. The general slope downwards to the right indicates the shift on the relationship with time.

This shift may be attributed either to changes in the magnitude of incoming and outgoing radiation, or to changes in the height and density of the long herbage. With the advance of winter, the herbage gradually decayed and collapsed, and the protective effect of the cover in comparison with the short sward declined.

There are two exceptions to the general angle of slope. The first is the $>47°$ class between periods A and B. Since this class was represented by only 4

values in period A and 3 in period B, little emphasis can be laid on the apparent divergence. The second is the upward shift common to all classes between periods D and E, i.e. in March 1954. This could be attributed to changes in the balance of radiation with the advance of spring, or to regrowth of the long herbage and a consequent increase in the relative protective effect. Regrowth in the long sward would be expected to start earlier and to proceed more rapidly than in the short sward, since the vigour of individual plants in the latter was reduced by repeated cutting in the previous autumn.

This reversal was not recorded in 1954–55. Records in 1953–54 did not end until March 23, while in 1954–55 they ended on March 13. Moreover, general night temperatures were increasing rapidly towards the end of the period of recording in 1953–54, while in 1954–55 the normal spring rise in temperature had barely begun by mid-March.

Considering all periods together for each winter, and introducing a variable x, where x represents the date and is measured in days from January 13, these relationships may be summarized in regression equations as follows:

1953–54

$d = 13 - 0{\cdot}29m - 0{\cdot}035x + 0{\cdot}00023x^2$. Standard error of estimate $\pm 1{\cdot}5$

1954–55

$d = 12 - 0{\cdot}32m - 0{\cdot}030x$. Standard error of estimate $\pm 1{\cdot}1$

where d and m are in °F. The values for the standard errors are probably underestimates, as no allowance has been made for the effects of day-to-day auto-correlations.

The records demonstrate that the protective influence of a dense herbage cover against extremes of night temperature in winter may be of considerable magnitude. The degree of protection was greater in early winter and when night temperatures were generally low. The observed temperature differences are likely to be of importance in connexion with herbage growth and death, particularly with reference to the losses sustained by standing herbage saved as winter keep for cattle, and to the recovery of such herbage in early spring after winter grazing.

WORLD METEOROLOGICAL ORGANIZATION

Second Conference of the Commission for Maritime Meteorology

The Commission for Maritime Meteorology of the World Meteorological Organization held its Second Session at Hamburg in October 1956. Although this was only its Second Session under the auspices of the World Meteorological Organization, the Commission was previously a technical body of the International Meteorological Organization and it held its first Conference as early as 1907. The Hamburg conference took place at the Seewetteramt, maritime head-quarters of the West German Meteorological Service. This Office is situated not far from the site of the former Deutsche Seewarte which was always such an active organization in maritime meteorology until it was destroyed during the last war. The impression one gathers is that the Seewetteramt is similarly making every effort to meet the meteorological needs of the mariner.

The arrangements for this Conference were admirable. From the main conference room one had a fine view of the River Elbe with its busy docks and shipyards. There were 23 nations represented at the Conference and no less than 18 of the delegates had seen considerable sea service either as meteorologists or as oceanographers. Two of the delegates were Port Meteorological Officers, from Cape Town and Hong Kong respectively. A nautical atmosphere was therefore much in evidence.

The conference lasted a fortnight and the discussions covered the whole field of maritime meteorology. Probably the most important question was that of the voluntary observing ships; evidence was produced that the total number of such ships in the world has increased since the last conference of the Commission for Maritime Meteorology in 1952, from about 2,400 to about 2,800. All meteorological services seem to agree that there is, nevertheless, a need for more reports from ships at sea, particularly from those areas where shipping is sparse. The Commission therefore recommended that a special effort be made to increase the number of "auxiliary" ships to make "non-instrumental" observations with the addition of pressure and temperature readings when in these particular oceanic areas. The intention is that the ships' own instruments will be used, provided their accuracy has been checked by the Port Meteorological Officer. Such ships will indicate that the barometric pressure reading is only accurate to the nearest millibar, by using the code group PPXTT. A recommendation was made about recruiting voluntary observing ships flying the "flags of convenience" of Panama, Honduras, Liberia and Costa Rica, in view of the large number of such ships which are now trading in all oceans. It was also recommended that all meteorological services encourage shipowners to supply their ships with good quality barometers and thermometers. The Commission recommended that all countries be urged to increase their number of "selected ships" and that ships should be encouraged to continue sending radio weather messages when they are in coastal waters. It was recommended that a simplified uniform address be used for ships' radio weather messages addressed to the shore; there is at present a multitude of such addresses in use, many of which are lengthy and thus not only lengthen the message but cost money.

The Commission recommended ways and means by which voluntary observing ships could best contribute to the programme of the International Geophysical Year. For example, in addition to the continuance of the "selected ship" scheme, Port Meteorological Officers in all ports are to visit as many ships as possible with the object of ensuring that meteorological observations of one kind or another are made during the International Geophysical Year in the relevantly unfrequented waters of the Southern Ocean, South Pacific, Indian Ocean and central Southern Atlantic. Special forms for recording the observations aboard "auxiliary" ships have been drawn up and detailed instructions as to the type and quality of the observations which are required will be promulgated. The Commission also provided for a special form on which observations from ships during the International Geophysical Year can be tabulated in a uniform manner and forwarded to World Meteorological Organization Headquarters for international scientific purposes.

For the application of meteorology to a seaman's duties, a working party of the Commission has, since 1952, been compiling an international booklet *Meteorological care of cargo*. This booklet is intended to explain to ships' officers in simple terms how best to apply meteorological principles to the care of the cargo in the hold of a ship and it has now been recommended by the Commission for publication. A representative of the British Chamber of Shipping who attended the Conference by invitation inferred that such a booklet would be welcomed by the shipping industry. To assist meteorological services in providing the best possible radio weather service for seamen, the Conference recommended the use of a short and simple forecast code for use by those countries which are at present unable to carry out the agreed international practice of issuing forecasts in English as well as in their own language. The reason that English is selected for this purpose is that it is a language generally understood by seamen.

Steps were taken at the Conference to overcome the confusion which exists at present owing to the various uses of the word storm, e.g. storm force wind as used in the Beaufort scale, storm warning, tropical storm, thunderstorm, magnetic storm, etc. Some confusion is also caused because of the use of moderate gale in the Beaufort scale for a force-7 wind, whereas gale warnings are only issued for winds of force 8 and above. After very lengthy discussion the conference decided that the best answer as a compromise solution, which does at least eliminate some of the confusion, was to make some amendments to the Beaufort scale, which has been in force since 1807, and their recommendations are as follows:—

force 7 to be "near gale" instead of "moderate gale",
force 8 to be "gale" instead of "fresh gale",
force 9 to be "strong gale" as at present,
force 10 to be "storm" instead of "whole gale"
and force 11 to be "violent storm" instead of "storm".

The Conference also recommended that the term gale warning be used with reference to winds of force 8 and 9 only and storm warning for winds of force 10 and above in temperate latitudes and that the term warnings of tropical cyclones should be used as necessary and appropriate in tropical areas.

At a conference in London in 1952 the Commission had recommended the introduction of a revised international Ice Nomenclature, and after some amendments had been made to this at the request of certain countries bordering the Baltic, this new nomenclature was adopted for international use in 1956. At the Hamburg Conference a small committee of ice experts

made a selection from all the available photographs which were made available by various nations, in order to illustrate this nomenclature. Steps are being taken to publish a limited edition of these illustrations in the first instance as a matter of urgency for use during the International Geophysical Year, because of the great interest in ice observations both in the Arctic and Antarctic as part of that programme.

Many of the maritime countries, notably Germany, Holland, the United Kingdom and the United States of America, produce marine climatological atlases of oceanic areas and other information for the benefit of shipping and also for research purposes. In order to get the best out of such information, which is contributed to by the voluntary observing ships of various nations, it is necessary that some international co-operation be achieved. For example, it is sometimes desirable to use data provided by the ships of other countries in order to "complete the picture" in areas where shipping is sparse. It is also desirable to have some uniformity in the manner in which maritime data are portrayed in climatological atlases. This is particularly important now that the World Meteorological Organization is considering a project for a world climatological atlas. This question is rather complicated and although it has already been given quite a lot of consideration no definite conclusions have yet been reached. The Commission therefore referred it to a Working Group for continued study.

Other questions considered by the Commission included:—a code for reporting sea ice from ships, shore stations and aircraft; sea temperature and rainfall observations at sea; illustrations of cloud forms and the provision of blank weather maps for use by voluntary observers at sea on an international basis; and liaison with other international bodies, e.g. the Food and Agricultural Organization in connexion with the provision of meteorological information for the fishing industry.

During the course of the Conference a series of three lectures was given on the subject of meteorology as applied to the navigation of ships. All the delegates had the opportunity of thoroughly inspecting the German Fishery Research Ship *Anton Dohrn* and lectures illustrated by films were shown concerning the work of this ship and in particular the forecasting service which she provides, alternately with a similar vessel *Meerkatze*, for the German fishing trawlers operating in far northern waters. Each of these vessels carries a fully qualified meteorologist. In addition to fishery research work, the ships do a certain amount of meteorological research and they have on board a doctor and fully equipped hospital for dealing with injured trawlermen and facilities for carrying out machinery repairs etc. to trawlers if required.

Delegates were also taken on a tour of the extensive docks of Hamburg and were very hospitably entertained by their German hosts on several occasions.

The conference was presided over by Cmdr. Frankcom; the British delegation consisting of Mr. Shellard of the Meteorological Office and the Director of the Naval Weather Service. At the conclusion of the Conference Dr. H. Thomsen of Denmark was elected President. Dr. Thomsen is an oceanographer as well as a meteorologist; he was aboard the Danish research ship *Dana* during her world cruise 1928–30, and he is also a keen yachtsman.

Meeting of the Working Group on Sferics and Second World Symposium on Atmospherics at Zurich 1956.

A meeting of the World Meteorological Organization Working Group on Sferics, a working group formed under a resolution of the Commission for Aerology, was held in Zurich on October 29 to 31, 1956. The working group was attended by Prof. Dr. J. Lugeon (Chairman) (Switzerland), Mr. L. A. Pick, (United States of America) and Mr. A. L. Maidens (United Kingdom). The fourth member, Mr. L. S. Mathur (India) was not able to attend.

Representatives of interested authorities in France, the United States of America and East and West Germany also attended the meeting which, in consequence was considered as forming the Second World Symposium (the first symposium was held in Zurich in 1953) on the many and varied topics embraced by the term Atmospherics. Both meteorological and radio interests were covered.

The forthcoming International Geophysical Year naturally occupied much of the discussions, and plans were made for the compilation and exchange of

MEMBERS OF THE COMMISSION FOR MARITIME METEOROLOGY OUTSIDE THE SEEWETTERAMT AT HAMBURG

MEMBERS OF THE WORKING GROUP ON SFERICS AND THE SECOND WORLD SYMPOSIUM ON ATMOSPHERICS

THE INTER TROPICAL CONVERGENCE ZONE TO THE NORTH-WEST OF SHARJAH, JULY 27, 1956

(See p. 155)

all forms of information based on measurements of the radio signals generated by lightning flashes. This included not only the location or bearings of thunderstorms but also measurements, in various forms, of atmospheric noise, direct observations of thunder heard and the study of atmospheric wave forms.

More generally, recommendations were agreed to encourage the development of sferic observations and to stimulate international co-operation of larger sferic networks than would be possible within the confines of single countries. At the request of the Commission for Aerology the meeting also reconsidered the accuracy with which thunderstorms should be located for aviation purposes, and expressed this in the form of the necessary spacing of sferic stations in the light of the Swiss, French and British trials of 1954.

The exchange, during the symposium, of views and information by experts in both the meteorological and radio fields proved most interesting and profitable. The hospitality of Prof. Dr. Lugeon and of the Swiss Meteorological Service, with most efficient secretarial services, ensured the success of the meeting.

NOTES AND NEWS

Field Studies Council.—A one-week residential course "Weather and Flight" on meteorology and aeronautics has been announced for July 3–10, 1957 at Preston Montford Hall Field Centre, near Shrewsbury.

Instructors:

Meteorology	R. S. Scorer, M.A., Ph.D.,	Imperial College
	C. E. Wallington, M.Sc.,	Meteorological Office
Aeronautics	F. G. Irving, M.Eng.,	Imperial College.

There will, in addition, be six special evening lectures by well known experts on colour photography, meteorological research flying (Mr. R. J. Murgatroyd, Meteorological Office), jets, soaring, and the flight of locust swarms and birds. Films will be shown.

The main course is intended to explain the basic principles of cloud physics and air dynamics and to interpret in terms of them the natural phenomena of weather and the artificial phenomena of flight. Knowledge of mathematics, though obviously helpful, is not essential. Opportunities for discussion will be plentiful. The current weather will be studied daily. Cameras should be brought if possible. There will be a visit on one day to the Midland Gliding Club, with opportunities for flight if the weather is suitable.

The fee for the course will be about £8.

Further enquiries should be addressed to The Warden, Preston Montford Field Centre, Montford Bridge, Near Shrewsbury.

The course has been organised jointly by the Field Studies Council and the Royal Meteorological Society, with the generous support of the Royal Aeronautical Society.

Rainfall at Sharjah, Summer 1956

The rainfall recorded at Sharjah, Oman, Persian Gulf, during the summer of 1956 is noteworthy. The details are given below. All times are in local zone time, i.e. G.M.T. plus four hours.

June		
29th	Trace	Slight rain at 0030 hr.
30th	Trace	Slight rain at 0200 hr.
July		
13th	0·6 mm.	Slight shower at 2030 hr., lightning to the south.
22nd	Trace	Slight shower at 1830 hr., thunder heard from 1600 hr.
23rd	Nil	Thunderstorm and showers to the south-east–south at 1710–1900 hr.
24th	Trace	Slight shower at 1615 hr.
25th	Trace	Slight shower at 0700 hr., slight rain at 1830–2200 hr., lightning east–south-east 2000–2100 hr.
26th	12·3 mm.	Intermittent slight rain from 0800 hr., continuing moderate 1800–1900 hr. then continuing slight to 2200 hr.
27th	2·7 mm.	Slight shower at 1230 hr., moderate shower at 1500 hr.
28th	Trace	Slight shower at 1430 hr., adjacent showers to 1730 hr.
29th	Trace	Adjacent shower 0900–1000 hr., slight rain 1700–2400hr.
30th	Trace	Slight shower at 0700 hr.
August		
	Nil	
September		
12th	5·4 mm.	Thunderstorm at 1645–1715 hr.

Total rainfall = 21 mm.

During the previous seven summers only 0·6 mm. of rain was recorded. Indeed 25 out of the 28 months, June to September, 1949 to 1955, were rainless. The monthly rainfall measured 0·3 mm. in August, 1949 with a shower on 26th, the same amount in July, 1950 with showers on the 17th, 28th and 30th, and a trace in August, 1955 with slight rain on 19th.

A Meteorological Office publication, "Weather in the Persian Gulf and Gulf of Oman", gives the rainfall for the five-year period 1933–37 as nil for the months May to October.

It is clear that the rainfall in the summer of 1956 was quite unusual. Local people say that so much rain has not been experienced in the summer months since 1939, but the amount which fell then is not known as the records are not available.

The photograph facing p. 155 was taken on July 27th, 1956, when the inter-tropical convergence zone lay along the Trucial Coast, just north-west of Sharjah.

E. W. SMITH

REVIEWS

The orientation of dunes in Britain and Denmark in relation to wind. By S. Y. Landsberg. *Geogr. J., London,* **122,** 1956, pp. 176–189. Royal Geographical Society, London.

The June number of the *Geographical Journal* contains the following article of meteorological interest.

Dr. S. Y. Landsberg studies the growth of dunes using Bagnold's result that the rate of transport of sand is proportional to $(V-10)^3$ where V is the wind speed in m.p.h. A sand-transport wind rose is built up by multiplying the frequency of winds of a given speed from a given direction by this transport factor. Good correspondence with the directions of formation of dunes in Britain and Denmark is found except for Culbin Sands (Elgin) and Fowie (near Aberdeen); it is shown that the local topography at these places renders the transport rose for the nearest wind observing station inapplicable.

G. A. BULL

Observatoire de Haute-Provence. 10 in. × 7½ in., pp. 23, *Illus.,* Centre National de la Recherche Scientifique, 1956.

We are indebted to the Cultural Service of the French Embassy, London, for a copy of a pamphlet on the new astronomical observatory recently constructed by the Centre National de Recherche Scientifique.

The site of the observatory, which is at St. Michel l'Observatoire, near Forcalquier, Basses Alpes was, it is explained, selected on meteorological considerations. The major work of the Observatory is naturally astronomical and the pamphlet is mainly devoted to that subject. However, work on the optical phenomena of the upper atmosphere is being actively pursued under the direction of Prof. Dufay. The subjects are the light of the night sky and twilight illumination with a view to determine the height of the luminescent layers and to study their variations and the physics of the phenomena. The pamphlet is beautifully illustrated with photographs of the Observatory and of astronomical objects taken from the Observatory.

G. A. BULL

HONOURS AND AWARDS

Dr. J. Glasspoole, Head of the British Climatology Branch of the Meteorological Office, was on March 13, 1957 elected an Honorary Member of the Institution of Water Engineers by the Council of the Institution.

OFFICIAL PUBLICATIONS

Five-year summaries of upper air data

The prices of the forthcoming addenda described in the *Meteorological Magazine* of February 1957 will probably be between 1*s.* 0*d.* and 1*s.* 6*d.* each (exclusive of postage).

ERRATUM

The scale of the chart reproduced on pp. 68, 69 and 70 of the *Meteorological Magazine* for March 1957 is wrongly marked and is intended to represent 100 miles.

METEOROLOGICAL OFFICE NEWS

W.R.A.F.V.R. Meteorological Section.—It was announced in Air Ministry Orders dated March 20, 1957, that the undermentioned non-commissioned officers in the Women's Royal Air Force Volunteer Reserve, Meteorological Section, had been granted the Air Efficiency Award. We offer them our congratulations.

Sergeant M. H. Marsh　　　　Sergeant P. F. Parker

WEATHER OF MARCH 1957

Pressure was 18 mb. below normal near the Azores in mid Atlantic, the "Icelandic" depression being transferred a thousand miles south to be represented by a lowest monthly mean pressure of 994 mb. about 49°N., 31°W. For the fourth successive month this represented much greater intensity of cyclonic activity than normal. It was a greater southward displacement than in February: the position in December and January had been close to normal. Frontal wave developments in March originated repeatedly well south in and near the Gulf of Mexico. For much of the month depressions failed to penetrate NE into the Barents Sea. Pressure was above normal over all the polar regions in a region of generally high pressure extending from China to the Hudson's Bay and South Greenland. There were regions of below normal pressure (anomalies −5 mb.) near the Caspian Sea and in the N. Pacific depression, which was about its normal position near the Aleutians.

Western Europe enjoyed a mild month with the persistent southerly winds, bringing anomalies of +3 to +5°C. in France and England and +6°C. at Spitsbergen. The Central Arctic and further part of polar basin is believed to have been rather colder than normal and near the northern Urals in continental air the mean temperature for the month was 7 to 10°C. below normal. As in February, most of the northern part of N. America, including the region of the Canadian cold pole, was less cold than normal (anomalies of surface temperature reached +5 to +6°C. in northern Quebec). It seems that by March the principal cold pole, though subject to erratic alternations between positions near the Canadian Archipelago and over Siberia, was mostly in the Siberian Arctic.

Temperatures were below normal over southern U.S.A. and the Middle West and probably over a wide area of the western and middle Atlantic including Iceland and South Greenland.

No remarkable features were noticed in the rainfall distribution, apart from considerable excesses in Germany, on the coast of Egypt and most inland districts of India. Unusual snowfalls were reported several times during the month in northern Texas and neighbouring regions just east of the Rockies.

In the British Isles a persistent south to south-easterly air stream maintained exceptionally mild weather for the time of year and brought a number of fronts of varying intensity across the country although depressions kept mainly to the west and north.

For the first four days weather in England and Wales was mostly dry and mild but rather foggy. Day temperatures rose well above normal on the 3rd, reaching 60°F. in places, but there was some air frost and fairly widespread

ground frost that night—at Cardington temperature fell to 25°F. in the screen and to 18°F. on the grass. Fog was widespread and locally dense on the 4th and 5th, especially in the Midlands, and persisted throughout the day in many places. From the 5th until the 9th a succession of fronts from the Atlantic moved eastward across the country and weather was mostly cloudy with rain at times and early morning fog patches: the area of greatest rainfall was in the south-west, although on the 8th Eskdalemuir recorded a total of 0·83 in. in 12 hr. With the arrival of drier and sunnier weather from Spain temperatures on the 11th rose sharply into the sixties—more than 15°F. above the mid-March normal—and exceeded 65°F. locally from southern England to as far north as central Scotland. The temperature reached 71°F. at Llandudno and 69°F. at places as far apart as Mildenhall, and Cape Wrath (Sutherland) on the 12th, and on the Air Ministry Roof (London) on the 13th. Parts of England enjoyed a total of over 15 hr. sunshine on these two days. A warm front, associated with a complex Atlantic depression, brought a moister air stream over the country on the 14th with widespread rain. The mild cloudy weather lasted nearly a week; rain fell in most areas nearly every day, but substantial falls were confined mainly to Scotland; Cape Wrath had 3·27 in. in the 36 hr. ending 0900 on the 16th. A temporary influx of cooler air on the 20th brought snow to high ground in Scotland and showers to all areas. The showers were heavy locally in the north with hail and thunder. The following two days were fine and sunny with daily sunshine totals exceeding 10 hr. in some places. An active depression to the north of Scotland brought fairly widespread rain on the 25th and 26th as associated fronts moved across the country; thunderstorms developed fairly widely on the 26th. Rain areas moved across southern England on the 27th and 28th, in rather a flat pressure distribution, with temperature exceeding 60°F. in some places, but during the last three days of the month rain was mainly confined to the west of the country and temperature fell somewhat as winds backed towards the south-east.

Temperature was unusually high for March, and at many places the monthly average exceeded the April normals. Over parts of central England temperature was between six and seven degrees above normal and at Kew it was the warmest March since records began in 1871. Sunshine was below the average generally and at some places it was the dullest March on record. Whereas the mildness of the month has continued to keep the season about three weeks in advance of normal, stock and arable farmers have not been particularly fortunate; cultivation, spring sowings and plantings have been held up, and despite the fact that grass was plentiful the ground was often too soft for grazing.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	74	22	+5·6	103	−1	82
Scotland	72	19	+4·6	115	+1	62
Northern Ireland ...	64	29	+5·3	108	+4	57

RAINFALL OF MARCH 1957

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·06	58	*Glam.*	Cardiff, Penylan ...	...	...
Kent	Dover	1·26	60	*Pemb.*	Tenby	4·83	156
,,	Edenbridge, Falconhurst	1·22	49	*Radnor*	Tyrmynydd	5·16	96
Sussex	Compton, Compton Ho.	2·53	91	*Mont.*	Lake Vyrnwy	6·73	150
,,	Worthing, Beach Ho. Pk.	1·37	71	*Mer.*	Blaenau Festiniog ...	10·67	124
Hants.	St. Catherine's L'thouse	1·90	96	,,	Aberdovey	4·80	144
,,	Southampton (East Pk.)	2·06	90	*Carn.*	Llandudno	...	...
,,	South Farnborough ...	1·31	66	*Angl.*	Llanerchymedd ...	3·25	10[illegible]
Herts.	Harpenden, Rothamsted	1·18	57	*I. Man*	Douglas, Borough Cem.	3·78	128
Bucks.	Slough, Upton	1·07	61	*Wigtown*	Newton Stewart ...	4·20	122
Oxford	Oxford, Radcliffe ...	1·70	103	*Dumf.*	Dumfries, Crichton R.I.	2·56	86
N'hants.	Wellingboro' Swanspool	2·14	120	,,	Eskdalemuir Obsy. ...	5·30	108
Essex	Southend, W. W. ...	·88	57	*Roxb.*	Crailing	1·41	66
Suffolk	Felixstowe	...	...	*Peebles*	Stobo Castle	2·54	88
,,	Lowestoft Sec. School ...	1·68	104	*Berwick*	Marchmont House ...	1·84	69
,,	Bury St. Ed., Westley H.	1·76	93	*E. Loth.*	North Berwick Gas Wks.	1·91	10[illegible]
Norfolk	Sandringham Ho. Gdns.	2·33	123	*Midl'n.*	Edinburgh, Blackf'd. H.	...	...
Wilts.	Aldbourne	2·06	87	*Lanark*	Hamilton W. W., T'nhill	2·97	106
Dorset	Creech Grange	3·54	126	*Ayr*	Prestwick	3·94	169
,,	Beaminster, East St. ...	3·61	123	,,	Glen Afton, Ayr San. ...	4·76	11[illegible]
Devon	Teignmouth, Den Gdns.	2·88	111	*Renfrew*	Greenock, Prospect Hill	5·95	128
,,	Ilfracombe	...	...	*Bute*	Rothesay, Ardencraig ...	...	...
,,	Princetown	10·93	160	*Argyll*	Morven, Drimnin ...	5·62	116
Cornwall	Bude	3·10	127	,,	Poltalloch	...	...
,,	Penzance	4·87	152	,,	Inveraray Castle ...	...	...
,,	St. Austell	5·66	165	,,	Islay, Eallabus	4·23	111
,,	Scilly, Tresco Abbey ...	4·42	169	,,	Tiree	4·69	140
Somerset	Taunton	1·82	88	*Kinross*	Loch Leven Sluice ...	2·83	95
Glos.	Cirencester	2·75	115	*Fife*	Leuchars Airfield ...	...	...
Salop	Church Stretton ...	2·29	95	*Perth*	Loch Dhu	...	...
,,	Shrewsbury, Monkmore	1·58	95	,,	Crieff, Strathearn Hyd.	4·61	144
Worcs.	Malvern, Free Library ...	2·22	114	,,	Pitlochry, Fincastle ...	3·47	126
Warwick	Birmingham, Edgbaston	2·49	118	*Angus*	Montrose Hospital ...	2·18	105
Leics.	Thornton Reservoir ...	2·29	124	*Aberd.*	Braemar	2·29	77
Lincs.	Boston, Skirbeck ...	1·62	104	,,	Dyce, Craibstone ...	2·24	85
,,	Skegness, Marine Gdns.	1·51	91	,,	New Deer School House	2·83	109
Notts.	Mansfield, Carr Bank ...	...	...	*Moray*	Gordon Castle	2·74	118
Derby	Buxton, Terrace Slopes	4·50	109	*Nairn*	Nairn, Achareidh ...	3·31	180
Ches.	Bidston Observatory ...	1·74	92	*Inverness*	Loch Ness, Garthbeg ...	...	...
,,	Manchester, Ringway ...	...	...	,,	Loch Hourn, Kinl'hourn	8·45	9[illegible]
Lancs.	Stonyhurst College ...	3·91	106	,,	Fort William, Teviot ...	8·14	121
,,	Squires Gate	...	...	,,	Skye, Broadford ...	...	...
Yorks.	Wakefield, Clarence Pk.	1·29	72	,,	Skye, Duntulm	5·24	119
,,	Hull, Pearson Park ...	...	...	*R. & C.*	Tain, Mayfield	2·82	125
,,	Felixkirk, Mt. St. John ...	1·49	76	,,	Inverbroom, Glackour ...	...	...
,,	York Museum	1·66	99	,,	Achnashellach	...	...
,,	Scarborough	1·13	63	*Suth.*	Lochinver, Bank Ho. ...	3·89	10[illegible]
,,	Middlesbrough	·83	53	*Caith.*	Wick Airfield	...	...
,,	Baldersdale, Hury Res.	2·00	69	*Shetland*	Lerwick Observatory ...	...	...
Norl'd.	Newcastle, Leazes Pk. ...	1·15	56	*Ferm.*	Crom Castle	4·23	13[illegible]
,,	Bellingham, High Green	2·57	97	*Armagh*	Armagh Observatory ...	2·45	10[illegible]
,,	Lilburn Tower Gdns. ...	1·54	58	*Down*	Seaforde	4·43	15[illegible]
Cumb.	Geltsdale	...	...	*Antrim*	Aldergrove Airfield ...	...	...
,,	Keswick, High Hill ...	3·50	78	,,	Ballymena, Harryville ...	3·07	9[illegible]
,,	Ravenglass, The Grove	3·12	101	*L'derry*	Garvagh, Moneydig ...	...	...
Mon.	A'gavenny, Plâs Derwen	...	...	,,	Londonderry, Creggan	2·49	7[illegible]
Glam.	Ystalyfera, Wern House	3·68	110	*Tyrone*	Omagh, Edenfel ...	3·61	11[illegible]

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	Per cent of Av.
	...
3	156
6	96
3	150
7	124
0	144
	...
5	109
8	128
0	122
6	86
0	108
1	66
4	88
4	69
1	103
	...
7	106
4	169
6	113
5	128
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2	116
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3	111
9	140
3	95
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1	144
7	126
8	105
9	77
4	85
3	109
4	118
1	180
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5	94
4	121
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4	119
2	125
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9	104
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3	137
5	104
3	155
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